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TITLE A STUDY OF THE NOCTURNAL DRAINAGE FLOW OVER A SLOPING PLATEAU IN NORTH-CENTRAL NEW MEXICO

AUTHOR(S) Brent M. Bowen, Jean M. Dewart, and Fred G. Fernald

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Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

A STUDY OF THE NOCTURNAL DRAINAGE FLOW
OVER A SLOPING PLATEAU IN NORTH-CENTRAL NEW MEXICO

by

Brent M. Bowen and Jean M. Dewart
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

and

Fred C. Fernald
Physics Department
University of Denver
Denver, Colorado

I. INTRODUCTION

As part of the Environmental Surveillance Program at the Los Alamos National Laboratory, two permanent meteorological towers have provided over one and one half years of uninterrupted data. The Laboratory is located in the southern half of Los Alamos County in the North-Central Mountains of New Mexico (Fig 1). The Laboratory is situated on the Pajarito Plateau, on the eastern flanks of the Jemez Mountains with the Sangre de Cristo Mountains nearly 70 km to the east. The Rio Grande River flows south-southwestward between these mountain ranges, following a line from Española to Albuquerque (not shown).

The topography of Los Alamos County is shown in Fig 2 along with the locations of the two meteorological towers where the data for this study were collected. The Pajarito Plateau slopes from the Jemez Mountains east-southeastward to the Rio Grande Valley, and contains numerous "finger" mesas and canyons, which also slope east-southeastward. The sites of the meteorological towers, Occupational Health Laboratory (OHL) and Area G, are located along the plateau slope line, 9 km apart. The slope is approximately 2.5% between the sites, increasing to nearly 10% to the west-northwest of OHL and decreasing to nearly 0% to the east-southeast of Area-G.

The location of the Lab in complex terrain and the prevalence of clear skies and low humidity in the region promotes local wind systems. This

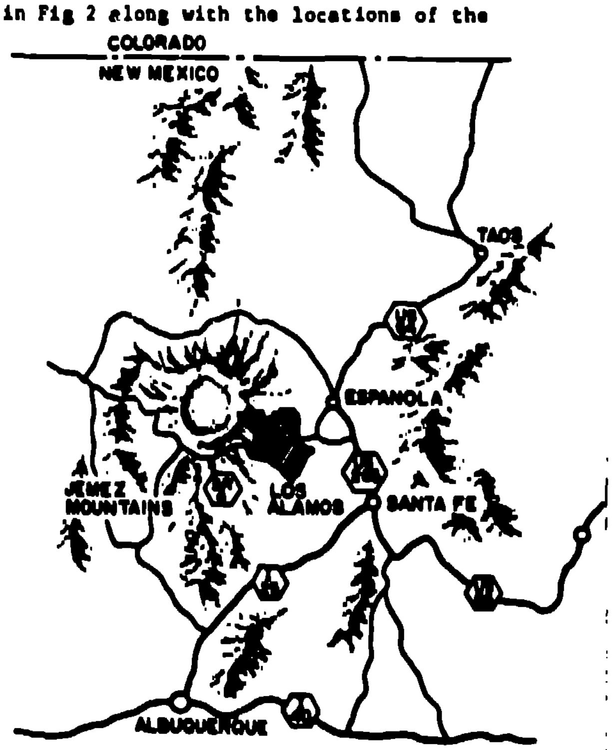


Fig 1 - Regional Location of Los Alamos

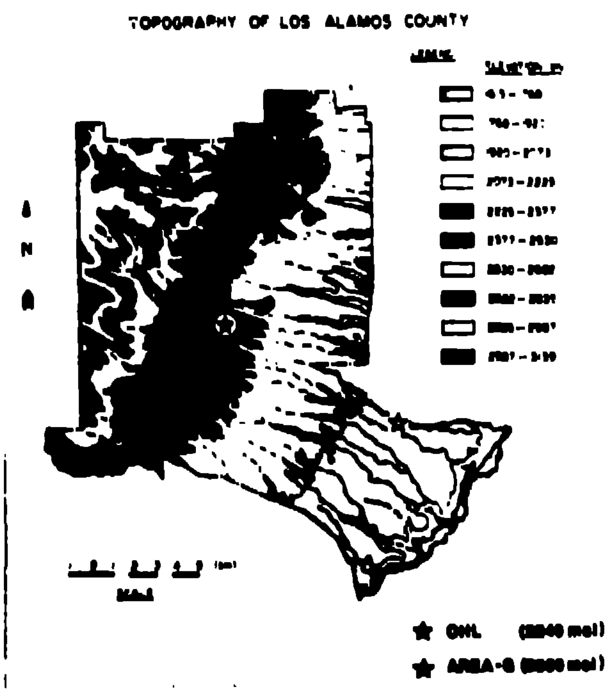


Fig 2 - Topography of Los Alamos County

paper primarily analyzes the drainage winds at Los Alamos. In addition, other local winds at Los Alamos are discussed: 1) upslope wind, 2) mountain-valley wind, 3) downslope flow due to terrain-forced thunderstorms, and 4) strong nighttime winds due to inversion decoupling.

II. BACKGROUND

It is well known that sloping terrain can cause local winds in the absence of strong gradient winds. One local wind, the slope flow, is caused by gravity and the differential heating/cooling between the air over the slope and air at the same altitude downslope. On clear nights, a drainage wind flows down the slope due to greater cooling of air near the surface compared to air at the same altitude downslope. Typically, slope winds have a velocity along the slope of 2-4 m/s (Defant). Above the slope wind layer, a weaker return flow exists. Recent modeling (Kao and Snodgrass) shows very little sensitivity in drainage wind speed due to change of slope angle. The same study shows that the maximum drainage wind speed is near 5 m above the surface in an idealized drainage case. The Coriolis force can turn the drainage wind, especially if the slope is long (e.g., long transport time). The period of motion in an inertia circle (T) is given by:

$$T = \frac{\Pi}{\Omega \sin \phi}$$

where Ω is the Coriolis parameter and ϕ is the latitude (Hess). Los Alamos has a latitude of 36°N, which makes the period about 20 hours. This means the Coriolis force can turn an air parcel at this latitude at a rate of 18°/hour.

A related flow is the mountain-valley wind. This wind is similar to the slope wind in that differential heating/cooling and gravity are the two forces. However, the mountain-valley wind is produced over long, broad valleys. During daytime hours, winds flow up the valley and during nighttime hours, winds flow down the valley. Since mountain-valley flows are of larger scale than slope flows, they lag behind slope flows (e.g., up-valley flows begin later after sunrise than the upslope flow and the down-valley flow starts later after sunset than the downslope flow). The shape of the valley's cross section and the inclination of the valley bottom have little effect on these winds (Defant). Other types of local flows in complex terrain include channeling of gradient winds and separated flow.

Since the Lab is located on a sloping plateau, which is part of the western boundary of a large valley, it experiences both slope flow and mountain-valley flow. Another study of local winds at Los Alamos (Clements and Barr) shows the existence of both drainage wind and mountain-valley wind. The drainage wind was shown to be important in the western Lab area and the mountain-valley wind to be important in the eastern area, near the valley floor of the Rio Grande Valley.

III. METHODOLOGY

1. Instrumentation and Siting. The OHL tower is 23 m high, standing on a one story (4 m) building. The building is surrounded by paved parking lots and a paved roadway. However, ponderosa pine trees (~20m) stand in all directions, making this a relatively rough site. The Area-G tower is 10.5 m, standing on a smooth, sandy mesa top. Only short grass and brush (~.5m) grow in the immediate area.

Identical instruments at the two sites measure horizontal wind speed and direction, vertical wind velocity, temperature and total solar insolation. An R. M. Young, Gill UVW anemometer (Model 27004) measures the three components of the wind. Thermistors equipped with blowers measure the air temperature and Epply pyramometers measure the incident solar radiation.

Each parameter is measured every 3 1/2 seconds by a home designed and constructed CMOS microprocessor. The microprocessor averages each variable for 15-minute periods. In addition, 15-minute averaged standard deviations are computed for the U, V, and W components of the wind. The 15-minute averaged wind direction and speed, along with their standard deviations, are then computed analytically from the U and V components.

2. Data. Data from the routine meteorological monitoring program at the Lab is analysed for this study. Specific time periods were chosen to describe the drainage winds at Los Alamos, and

data from both meteorological towers for these periods were analyzed. These periods are: all of 1980, June 1980, November 1980, fourteen days during June 1980, thirteen days during November 1980, and March 15-16, 1980. These time periods were selected to describe drainage winds on an individual day case study basis and for a monthly and annual average case. For these different cases, the data has been divided into daytime and nighttime periods with daytime defined by solar insolation measurement $\geq$ 0.05 ly/min.

In addition, individual days have been selected to describe two other local wind phenomena: forced downslope winds during topographically-induced thunderstorms and strong nocturnal winds due to vertical decoupling.

IV. ANALYSIS AND DISCUSSION

1. Annual 1980 Winds. The averaged 1980 windroses show a remarkable difference between OHL and Area-G (Figs 3 & 4). The greatest differences appear during the daytime. Approximately 23% of the daytime winds at OHL are from the SE and SSE due to the upslope wind at this site. Note that Coriolis force is important in deflecting the upslope wind since the slope is WNW to ESE. The daytime winds at Area-G, a site closer to the bottom of the Rio Grande Valley, show a maximum occurrence from the SSW and SW. This is caused by the Rio Grande up-valley wind. The up-valley wind is rather strong, with half of the SSW-SW winds over 5 m/s.

Some hint of the down-valley wind is also indicated by the 14% occurrence of winds during the day from the NNE-NE at Area-G. Hourly windrose analyses show that NNE-NE winds do occur generally for several hours after sunrise. This period coincides with the expected last few hours of the down-valley wind. Winds are also observed from the NNE and NE after sunrise at OHL, but with a smaller frequency of occurrence than at Area-G.

The nighttime drainage wind is clearly evident in the 1980 OHL windrose. Winds blow from the WNW-NW a total of 29% of the time. The drainage wind at Area-G is not as prominent, perhaps due to the Coriolis force turning the wind.

Fig 3

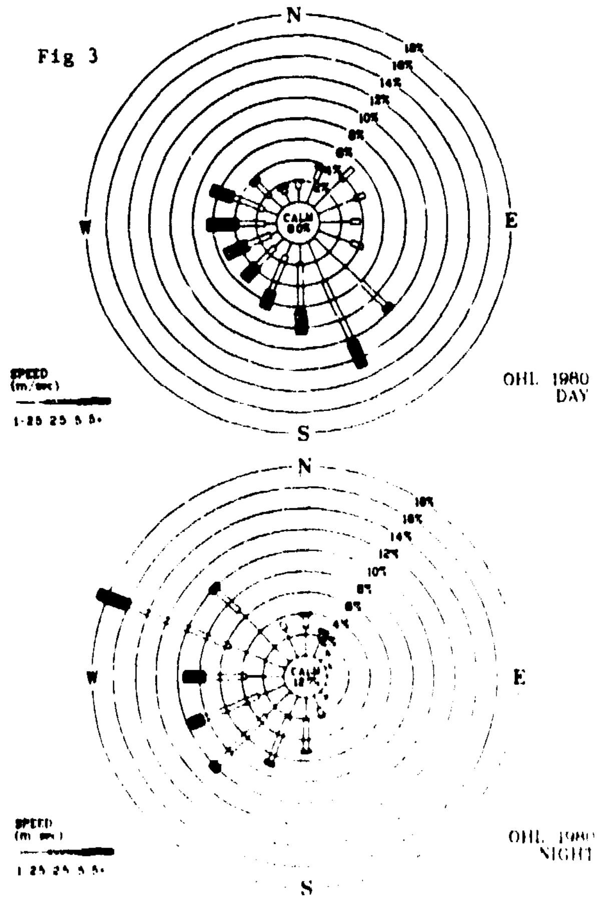
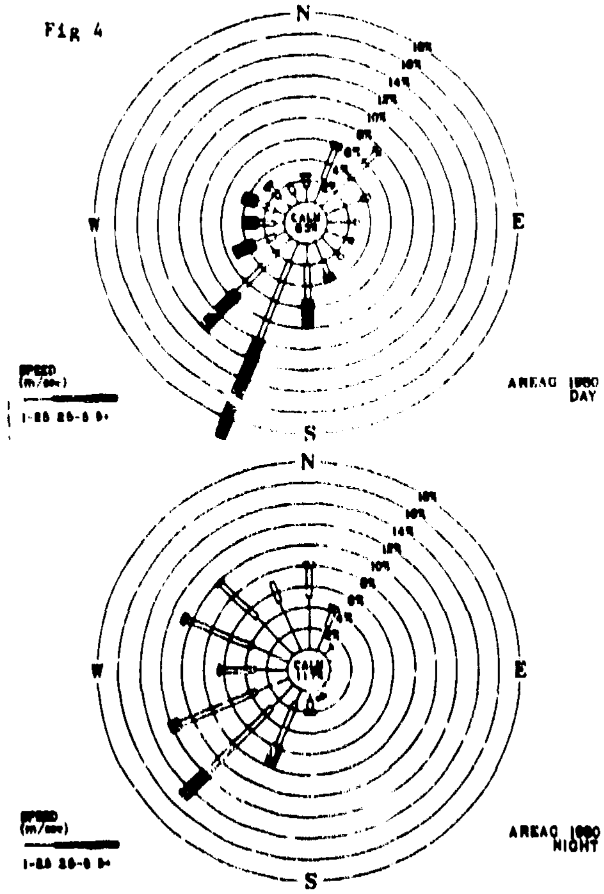


Fig 4



Area-G is close to the bottom of the slope: the draining air has a longer transport time. Therefore, the Coriolis force has a longer time to act, producing more northerly winds. A total of 28% of the nighttime winds are from the WNW-NNW. Another 13% of the winds at Area-G at night are observed to be from the N-NNE, but it is unclear whether these are due to the drainage wind, down-valley wind, or a combination of both.

2. Drainage Wind - March 15-16, 1981.

A typical night of drainage winds at OHL and Area-G is shown in Figs 5-6, respectively. As the slope cools after sunset, 1800 MST, the drainage wind begins at OHL at 18:15 and at Area-G at 18:45. Note that the direction of the drainage wind is WNW at OHL and more northwesterly at Area-G. The greater windspeed and smaller standard deviations of windspeed and direction during the night at Area-G are probably caused by the smaller surface roughness at Area-G.

The wind at Area-G changes after 22:00, becoming lighter, more northerly and erratic. From 07:00 until 09:00 on the 16th, the wind direction was between the north and east, indicating the Rio Grande down-valley wind. But, at OHL, the drainage wind continues the entire night, changing to a light easterly wind at 09:00. This may be the down-valley wind affecting the OHL site. Stronger, upper level southerly winds are brought down to both sites after 11:00, ending the localized winds.

3. Drainage Winds - June and November, 1980.

The months of June and November of 1980 are analyzed in detail due to the predominance of locally produced winds. Both months were characterized by light gradient winds and clear skies. Figs 7 and 8 show the day-night windroses for OHL and Area-G. As in the annual windroses, the June OHL daytime windrose has a relative maximum from the SE-SSE of 22% due to upslope flow. The daytime Area-G windrose shows a 36% occurrence of SSW-SW winds, indicating a prevalent up-valley flow. Of this 36%, 72% are greater than 5 m/s speed. At night, OHL shows an extreme maximum from the WNW and a secondary maximum from the NW. These two directions account for over 42% of all the wind directions observed at night. The drainage wind at Area-G is spread over 3 direction points (WNW-NNW) 40% of the time.

A more detailed look at the drainage days in June can be seen in Figs 9-10. These figures represent 14 days in June, 1980, in which drainage flow predominated over gradient flow. Note the abundance of sunshine and large diurnal temperature variations on these days. Also, afternoon southwesterly winds are common for both sites. An inspection of daily 500 mb maps for these days shows an average longwave trough over the Western U.S. and southwesterly winds over New Mexico. The afternoon winds are therefore due to the large scale flow.

The drainage wind starts at both sites around 19:30. The wind stays from the WNW at OHL

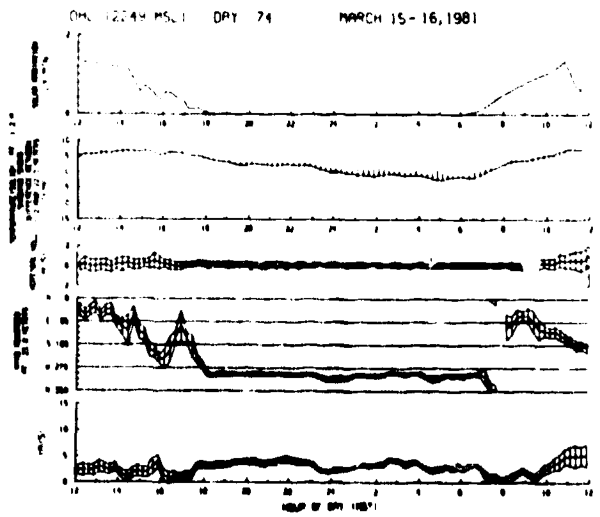


Fig 5 - Drainage Case Daily Summary for OHL

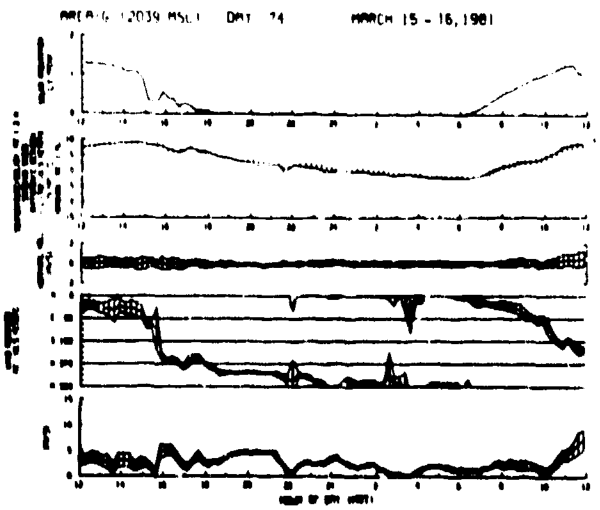


Fig 6 - Drainage Case Daily Summary for Area-G

Fig 7

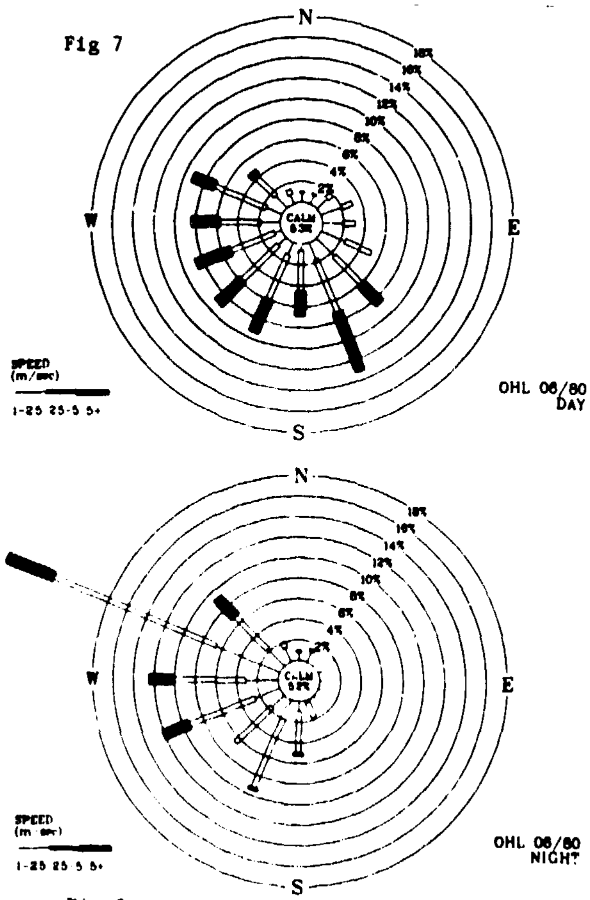
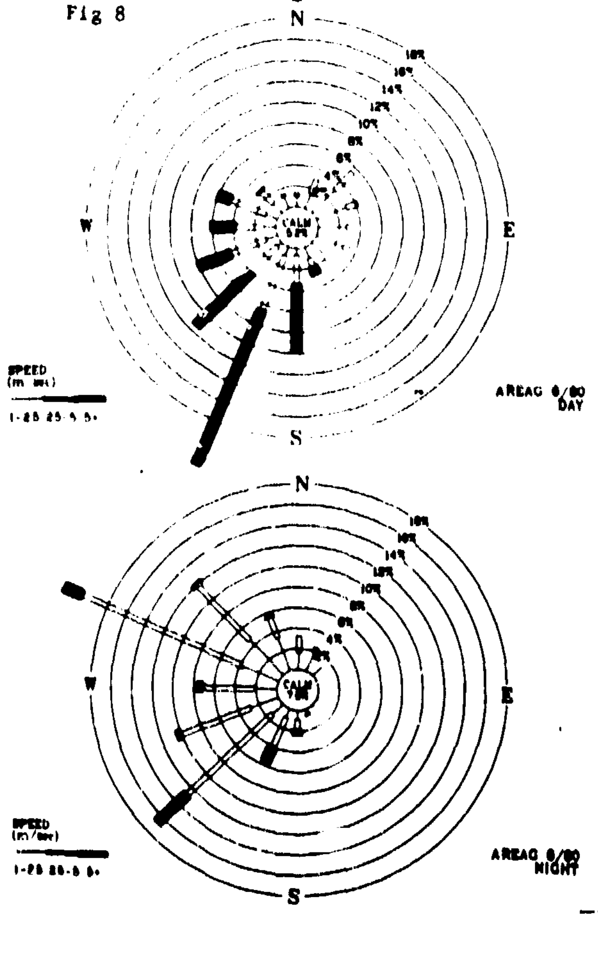


Fig 8



while the wind turns slightly at Area-G from WNW to NNW through the night. The drainage wind then gives way to the down-valley wind at Area-G by 05:30 and at OHL 45 minutes later. An upslope wind (SE) is then evident at both sites between 09:00 and 11:00. The atmosphere then becomes unstable enough to transport stronger upper-levels southwesterly winds down to the surface at both sites by 11:00.

A similar analysis was done for November, 1980. This month had many days with rather light gradient winds. Day-night windroses for

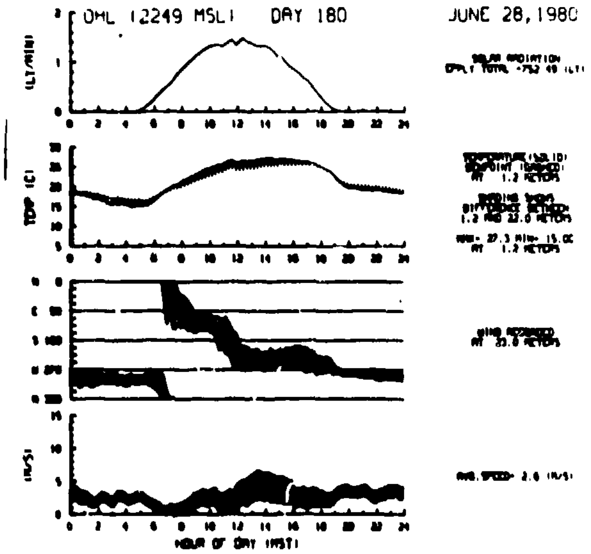


Fig 9 - OHL Average Summary for 14 Selected Days in June 1980

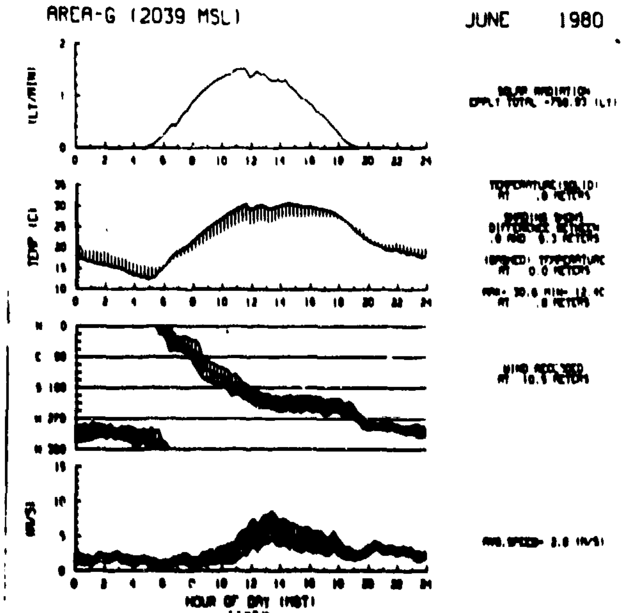


Fig 10 - Area-G Average Summary for 14 Selected Days in June 1980

Fig 11

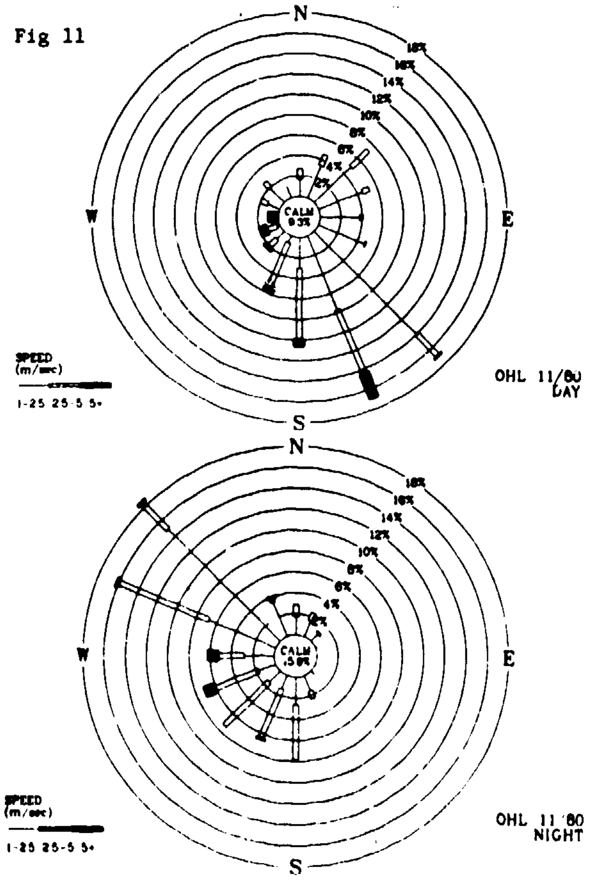
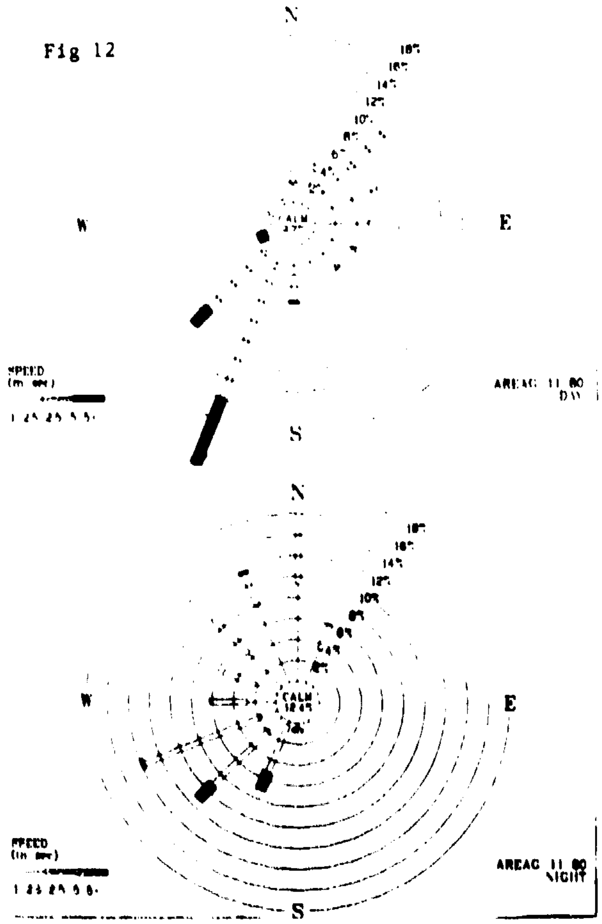


Fig 12



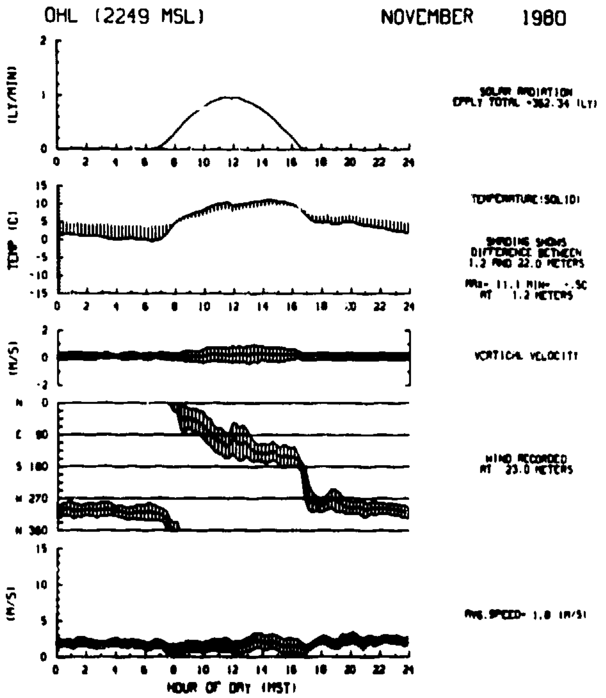


Fig 13 - OHL Average Summary for 13 Selected Days in November 1980

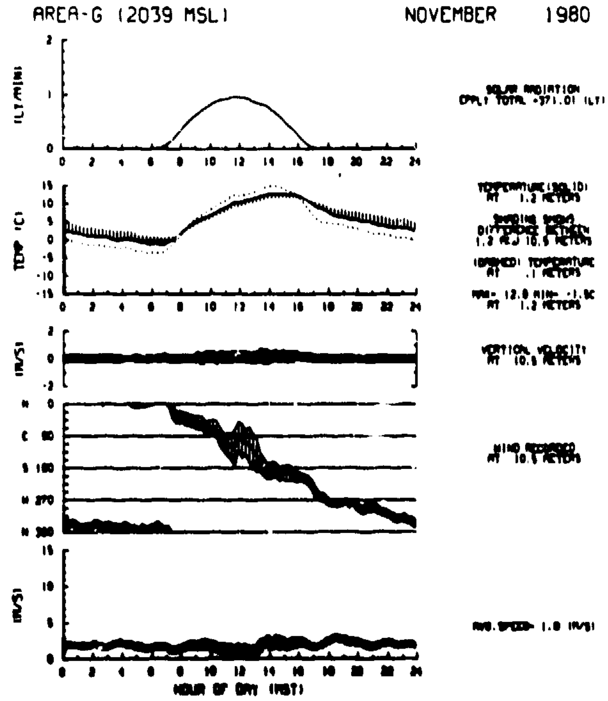


Fig 14 - Area-G Average Summary for 13 Selected Days in November 1980 these days are shown in Figs 11 and 12. Note the striking evidence of upslope winds at OHL. A total of over 44% of the daytime winds at OHL were SE, SSE, S. Most of these winds were under 5.0 m/s. Conversely, Area-G shows a maximum frequency (35%) of winds from SSW and SW, indicating the importance of the up-valley wind here. Unlike OHL, only few winds were directed up the slope. There also appears to be a secondary maximum from the NE, at Area-G, probably due to the down-valley wind for several hours after sunrise. The nighttime windroses show that a drainage wind was prevalent at both sites. Over 34% of the winds were WNW and NW at OHL, while nearly 36% at Area-G were NW, NNW, and N. The slight turning of the drainage wind at Area-G indicates the greater importance of the Coriolis force over longer transport times (e.g., Area-G is further down the slope). Another 6% of the winds at Area-G are from the NNE, probably indicating the presence of the down-valley wind.

4. Local Thunderstorm Flow. The Los Alamos area receives many thunderstorms in the summer due to the proximity of the mountains to the west. An average of 58 thunderstorm days per year occur according to local climatological records. Thunderstorms generally develop over the mountains in the afternoon or early evening due to the increased thermodynamic instability from solar heating. Many of the thunderstorms are very weak causing very little or no precipitation. In addition, on many summer days, thick cumulus clouds develop over the mountains producing no thunder. The thunderstorms or clouds generally move east over the Pajarito Plateau following upper level winds.

A local wind occasionally forms as a result of the thunderstorms. As the clouds move down the plateau, a strong zone of differential heating occurs due to the blocking of solar insolation by the clouds. The clouds then dissipate as they move toward the Rio Grande Valley. A strong wind then develops downslope over the plateau. Fig 15 shows an example of this situation at OHL. On this day, clear skies are evident in the morning hours at both sites. The winds are light (<2m/s) from the NE-SE. As the thunderstorm moves over the plateau, decreased solar insolation allows the temperature to drop at both sites. The temperature gradient across the plateau causes a strong wind (~9m/s) to blow generally from the west. The effects due to a thunderstorm at Area-G lag the effects at OHL by 15 to 30 minutes. Also, 5.33 mm of rain fell at OHL while no measureable rain fell at Area-G.

This case typifies the wind forced by locally produced thunderstorms. Many weak thunderstorms, which form over the mountains, do cause locally strong westerly winds. However, stronger thunderstorms can cause brief strong winds from other directions.

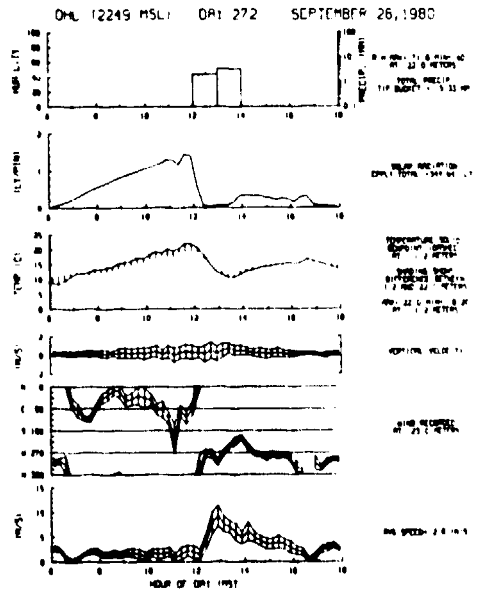


Fig 15 - Thunderstorm Flow Case Daily Summary for OHL

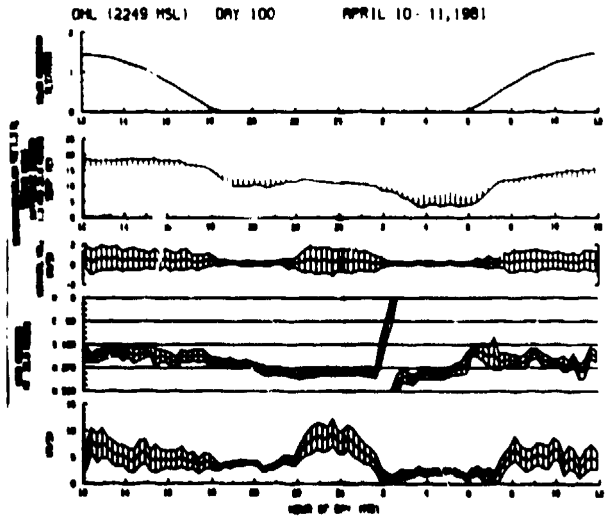


Fig 16 - Nocturnal Wind Maximum Case Daily Summary for OHL

5. Nighttime Wind Maxima

Another common local wind at Los Alamos is the nighttime wind maximum. Blackadar (1957) showed that a sharp supergeostrophic wind maximum is frequently observed at night below 3000 ft, due to the initiation of a low-level inversion shortly after sunset. It is also well known that winds at tower level (~75 m) are stronger during nighttime hours. Fig 16 presents data for an evening at OHL in which the wind maximum was evident. On April 10, under sunny skies, strong large-scale southwesterly winds blew at both sites. After sunset, the windspeed diminished to under 5 m/s at both sites. However, after 2200, the winds increased to near 10 m/s at OHL. At the same time, the winds at Area-G remained less than 5 m/s.

The nocturnal wind maximum at Los Alamos is probably a result of the formation of an inversion, especially toward the valley. The inversion then decouples upper winds from the surface, allowing winds above the inversion to become at least as strong as geostrophic. As the winds above the surface increase, a strong wind sheer develops. This, in turn, causes strong winds to reach the surface, especially at the higher end of the plateau. The strong winds, as in the example presented, generally develop shortly after sunset at OHL. The winds usually subside later in the night as the inversion deepens and intensifies. The lower site, Area-G, experiences lighter winds, if any at all. Many times the nocturnal winds occur ahead of an approaching trough.

V. SUMMARY AND CONCLUSIONS

Local, terrain induced winds at the Los Alamos National Laboratory are shown to be important based on routine meteorological measurements. Two towers provide data on the sloping Pajarito Plateau; OHL, near the flanks of the Jemez Mountains and Area-G, near the Rio Grande Valley.

The nocturnal drainage wind (downslope flow) is shown to be common at both sites on relatively clear nights without strong gradient winds. The Coriolis force apparently turns the drainage wind by the time it reaches the lower site, Area-G. A daytime upslope wind is shown to be common at the higher OHL site, but the up-valley wind predominates at Area-G during the daytime. The down-valley wind is seen for several hours after sunrise at both sites, especially at Area-G.

Several other types of local winds were found at the Lab. One is a strong downslope wind during thundershowers due to differential heating. Another is a strong nocturnal wind maximum generated by the thermal decoupling of a nighttime inversion. This wind is more common and stronger at OHL.

ACKNOWLEDGMENTS

We wish to acknowledge Bill Olsen for his efforts in maintaining the meteorological instruments and towers. We also wish to thank Don VanEtten for his work in setting up the meteorological towers several years ago. Finally, we thank Verna Halloran for her skillful and quick preparation of this manuscript. This work was done under the auspices of the U.S. Department of Energy and the University of California.

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